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ANALYSIS OF HIGH-MULTIPLICITY EVENTS

E. S. Kokoulina [a,b], *A. Ya. Kutov* [c], *V. A. Nikitin* [a], *V. V. Popov* [d]

[a] Joint Institute for Nuclear Research, Dubna

[b] Gomel State Technical University, Gomel, Belarus

[c] Department of Mathematics Komi SC UrD RAS, Syktyvkar, Russia

[d] Skobeltsyn Institute of Nuclear Physics, Moscow State University, Moscow

The experimental studies of the high-multiplicity events in proton interactions are carried out at U-70 accelerator in Protvino. It is suggested that the collective phenomena can be discovered since the high-density matter can be formed in this very region. The collective behavior of secondary particles can manifest in the Bose–Einstein condensation of pions, Vavilov–Cherenkov gluon radiation, excess of soft photon yield and other unique phenomena.

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INTRODUCTION

The main results obtained by SVD-2 Collaboration within the last few years are presented in this report. The experiment is carried out at U-70 accelerator at IHEP, Protvino, Russia. From 2005 up to now the beam energy was reduced to 50 GeV owing to economical reasons. We study the multiparticle production in proton–proton and proton–nuclei interactions with the high multiplicity.

The mean multiplicity (determined as the mean number of secondary particles) at 50 GeV amounts about 5 charged and 2 neutral particles. They are, basically, pions. We are aimed to study the region with the multiplicity more than the mean multiplicity. We conjecture the multiplicity has the upper limit which is much less than kinematical one and can be reached at our experiment.

We think that the dense nuclear matter may be produced at U-70 energy of 50 GeV in the high-multiplicity region. That is why this region is the unique one. At present, the theoretical and experimental studies of the high nuclear density matter are very actual ones. The possibility of the existence of the phase transition is discussed very intensively [1–3]. The search for the critical point and the phase transition signals may forward the understanding of multiparticle-production nature. Our researches are useful to advance in this direction.

1. THE PROBLEMS OF THE HADRON COLLISIONS WITH HIGH MULTIPLICITY

At the beginning of our studies we assumed that in the high-multiplicity region new phenomena can be found. We expected that the collective behavior of secondary particles can manifest at this region of multiplicity. It is stipulated by the dense-matter formation [4].

The simulation of pp interactions at 70 GeV (energy of U-70) by using the Monte Carlo event generator, PYTHIA, has shown that the standard generator predicts values of the partial cross sections $\sigma(n_{\rm ch})$ at 70 GeV which are in reasonably good agreement with the experimental

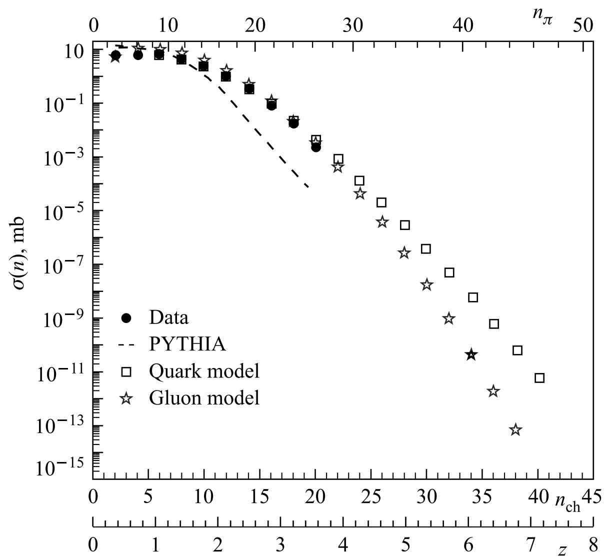

Fig. 1. The partial cross sections for pp interactions at 70 GeV: the experimental data (•) [5], MC PYTHIA (dashed line), quark (□) and gluon ($\star$) models

data at small multiplicity ($n_{\rm ch} < 10$), but it underestimates the values $\sigma(n_{\rm ch})$ by two orders of magnitude at $n_{\rm ch} = 18$ [4]. In Fig. 1 is seen the differences between the data [5], Monte Carlo predictions, quark [6] and gluon [7–11] models. These models significantly differed in their predictions, also.

The uncertainties in model description are staying up to now. The first data obtained at Large Hadron Collider (LHC) at high energies (900 GeV and 3.5 TeV) were compared with the different Monte Carlo event generators, and these codes have shown the noticeable deviations of theoretical and experimental values at the moderate multiplicity [12, 13]. We are not sure that at higher multiplicity the proposed description will be better. Evidently the exhaustive understanding of multiparticle production at hadronization stage is absent, and additional studies of this domain are required.

The absence of any discrepancies with data at high-multiplicity region was revealed by using the two-stage model for the description of multiplicity distributions in e^+e^- annihilation [14] from ten up to two hundred GeV. Later this model was modified for hadron interactions and had gotten the name the gluon dominance model. The two-stage model has confirmed fragmentation mechanism of hadronization, has indicated the active role of hard gluons and has given the good description of multiplicity distributions and their moments at the extreme multiplicity. Now the important role of gluons in multiparticle dynamics does not give rise to doubts, but the insight of their role has come not at ones.

It is known from Mirabelle data [4] that the longitudinal and transverse components of momentum of secondary particles in pp interactions are becoming close to each other at $n_{\rm ch} = 16$. We are interested what will occur with them at higher multiplicity? We see three scenarios for component behavior: 1) equality of them, 2) the longitudinal component will become more than the transverse one and 3) the longitudinal component will be smaller than transverse one.

2. THE SVD-2 SETUP

The experimental studies of the high-multiplicity events are carried out at U-70 accelerator in Protvino, Russia. Our setup, Spectrometer with Vertex Detector (SVD-2), consists of the following elements [4]. One of the main of them is microstrip silicon vertex detector. It has ten silicon planes and allows one to determine vertex of interaction and tracks of secondary charged particles with high precision. We have manufactured unique hydrogen target of small size. Our drift tube tracker has three modules with three plains for every module. It has the bigger acceptance than the vertex detector. Magnetic spectrometer consists of large magnet and 16 proportional chambers. Also we have Cherenkov counter and the electromagnetic calorimeter for the neutral-particle registration.

High-multiplicity events occur very rarely. For the suppression of the event registration with low multiplicity, we have designed and manufactured trigger, scintillation hodoscope. It makes signal for the selection of events with multiplicity higher than specified level. We registered events at trigger levels from $2\times$MIP up to $12\times$MIP.

Using the scintillation hodoscope, we have extended the multiplicity distribution from 16 (Mirabelle data) up to 24 charged particles (our experiment). The achieved value of the partial cross section is less by three orders of magnitude in comparison with Mirabelle value. The obtained distribution agrees well with the gluon dominance model (Fig. 2).

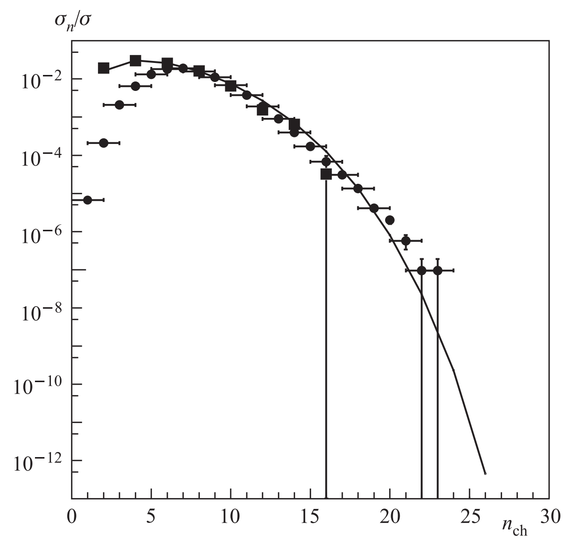

Fig. 2. Multiplicity distributions obtained at $E_p = 50$ GeV at Mirabelle (■) [5] and SVD-2 (●), the GDM prediction (solid curve)

3. THE COLLECTIVE PHENOMENA

In the extreme multiplicity region we search for the new collective phenomena of secondary particles. They have hadron nature as well as quark–gluon nature. That is why their investigations are important. We have analyzed events with the trigger-level equal to

$8\times$MIP and higher. The experimental angular distributions were obtained at two domains of multiplicity by using vertex-detector data without taking into account acceptance corrections and efficiency of the setup (at present this work is in progress): a) with the multiplicity more than eight and b) with multiplicity less than nine charged particles.

We have revealed the unusual shape of angular distribution in the a) case: two noticeable peaks, especially on the left at $\theta \approx 0.1$ rad. This distribution was described by the sum of the third order polynomial and two Gaussian functions (Fig. 3). The confidence levels of both peaks are equal to 3.5–4. In the b) case we do not observe any peaks.

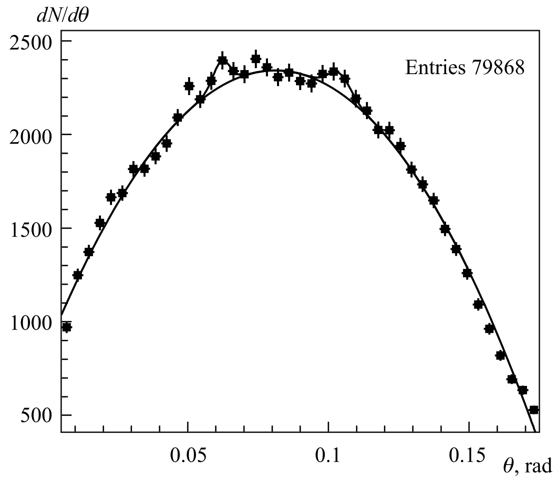

Fig. 3. The description of the experimental θ distribution by third order polynomial of background and by two gausses of peaks (events with high multiplicity)

If we assume that this hump structure is caused by Vavilov–Cherenkov gluon radiation, then it is possible to estimate the refraction index of hadronic matter [15]:

$$\cos\,\theta_{\mathrm{C}} = 1/\beta n, \tag{1}$$

where $\beta = p/\sqrt{p^2 + m_p^2}$ and n is the refraction index. At beam momentum $p = 50$ GeV from (1) the experimental value of the refraction index at 50 GeV is equal to $n = 1.0023 \pm 0.0003$. This value is very close to 1. Dremin [15] connects that behavior with the dilute parton system (quark–gluon gas). The opposite case $n \geqslant 3$ corresponds to a more density system (quark–gluon liquid).

In pp interactions mainly the lightest particles, pions, are formed. They are bosons. The more secondary particles are produced the smaller energy they have. V. Begun and M. Gorenstein [16] have proposed to search for Bose–Einstein condensation (BEC) of π mesons in the high-multiplicity events. They have shown that the pion-number fluctuations strongly increase and may give a prominent signal at approaching the BEC.

To reveal these signals, one needs to carry out the event-by-event identifications of both the charged and the neutral pions. An abrupt and anomalous increase of the scaled variance $\omega_0 = \langle(n_0 - \langle n_0\rangle)\rangle^2\rangle > /\langle n_0\rangle$, of neutral ($n_0$) and charged pion number fluctuations will be the signal of BEC.

To analyze ω_0 we have selected events with the charged multiplicity up to 24 and determined the number of neutral particles for every such an event. We thought that the number of neutrals will be ruffly proportional to charged multiplicity. But we observe maximum number of neutrals in the interval $n_{\rm ch} = 8-14$ (up to 16 neutrals in this region). This analysis is in progress.

The production of the high number of neutrals at the charged multiplicity $n_{\rm ch} \sim 10$ confirms the recombination mechanism of hadronization. According to this conception $q\bar{q}$ pairs of light flavors, up and down, are produced simultaneously. After that they recombine to neutral and charged pions. The formation of neutral pion occurs by the combination of the same flavor quarks ($u\bar{u}$ or $d\bar{d}$). The charged pions consist of quark–antiquark pairs of different flavors.

We suggest that the production of the high number of primary quark pairs in proton interactions favors the formation of the maximum multiplicity of neutrals and, obviously, high total multiplicity. Our experimental studies indicate to such a behavior. At the decrease of the primary quark pairs, the probability of formation of neutrals decreases. At high charged multiplicity region we observe small multiplicity of neutrals.

Very interesting and unexpected results of the manifestation of the collective behavior of secondaries were observed by DELPHI Collaboration at SPS in the Z^0-boson region [17]. The anomalous formation of soft photons at hadron channels was revealed. The rate of such photons exceeds the theoretical predictions by 4–7 times for charged-hadron channels and by 20–25 times for neutral-hadron channels.

We are planning to carry out the investigations of soft photon yield at SVD-2 setup. Our group works up the electromagnetic calorimeter for their registration. We carry out Monte Carlo simulation to manufacture the prototype of such a calorimeter. We plan to investigate the soft photon yield as a function of the number of charged and neutral hadrons at the high multiplicity region.

In accordance with the gluon dominance model, the formation of soft photons happens at the hadronization stage [11]. It may be assumed that such distinction in the yield of photons is stipulated by not the same way of their formation. Evidently the neutral mesons consisting of quark pair of the same flavor spend less gluon matter at their formation than charged pion, formed from the different flavor quarks. In the case of neutral pions more unused gluon material remained than in the charged ones. In both cases this additional gluon matter is reradiated through soft photons. Such behavior testifies to the recombination mechanism of hadronization.

CONCLUSION

Preliminary studies of collective phenomena of multiparticle production in pp interactions have been carried out. There are indications on the unusual behavior of the angular distributions in the high-multiplicity region for charged particles. The yield of neutral mesons as a function of charged multiplicity is also unusual. We plan to investigate the collective phenomena and to advance the explanation of multiparticle-production nature. These investigations have been partially supported by Russian Foundation of Basic Research Nos. 08-02-90028-Bel_a and 09-02-92424-KE_a.

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